5.9 RADIATION PRESSURE ON INTERPLANETARY DUST PARTICLES

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The force acting on an interplanetary dust particle due to solar radiation pressure at a distance R from the sun is given by

$$F_{rad} = \frac{\pi r^2}{c} \frac{R_o^2}{R^2} \int_0^\infty Q_{pr} \left[m(\lambda), x(\lambda)\right] s_\lambda \, d\lambda$$

with $R_o = 1$ AU, r the radius of the particle, $m(\lambda)$ its complex refractive index, c the velocity of light, λ the wavelength, s_λ the solar flux outside the earth's atmosphere per unit area and wavelength range. The function Q_{pr} is the efficiency factor of the radiation pressure as given by Mie-theory, which depends on the refractive index m and the size parameter x of the particle defined as the ratio of the circumference of the particle to the wavelength.

In figure 1 $Q_{pr}(m,x)$ is plotted versus size parameter x to give an impression of the properties of this quantity.

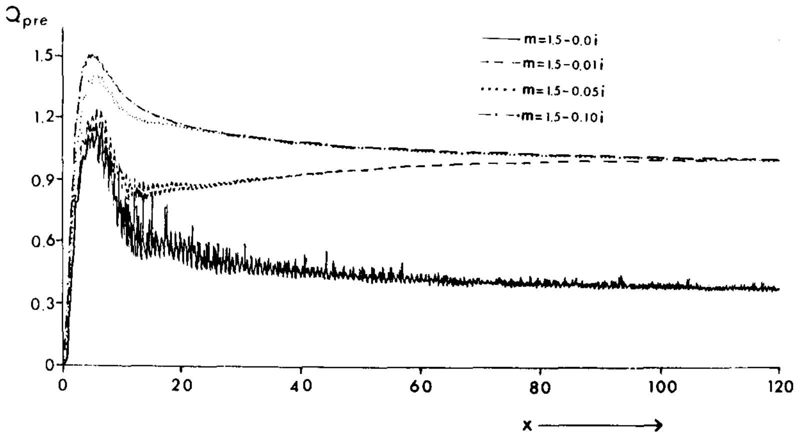

Fig. 1: Q_{pr} for different imaginary parts of the index of refraction; real part fixed ($\lambda = 0.53\ \mu$).

It is more convenient to use the quantity ß defined as the ratio of the force due to radiation pressure F_{rad} to the force of gravitational attraction F_{grav}

$$ß = \frac{F_{rad}}{F_{grav}} = \frac{A}{\rho \cdot a} \int_0^\infty Q_{pr} \, s_\lambda \, d\lambda$$

which is independent of the distance of the particle from the sun.

Here ρ is the density of the dust particle and the constant $A = 3R_o^2/4cfM_\odot$; f is the gravitational constant, and $M_\odot$ the mass of the sun.

The integral was evaluated using a computer program, which has been written to compute scattering functions of core-mantle particles (Giese, Schwehm, Zerull 1973) based on the theory of Güttler(1952). In this paper, however, only homogeneous spheres will be considered, because of the amount of data then to be taken into account a thorough discussion of the ß values for core-mantle particles would be beyond the scope of this short contribution and will be published elswhere. For the solar radiation flux, values given by Labs and Neckel (1970) have been used.

ß has been evaluated for different materials regarding the wavelength dependence of their complex index of refraction. The integration was carried out for every value of the radius over the whole range of wavelength from 0.2 µ to 50(100)µ.

In fig. 2 ß is plotted versus particle radius r for Obsidian and Andesite. The shape

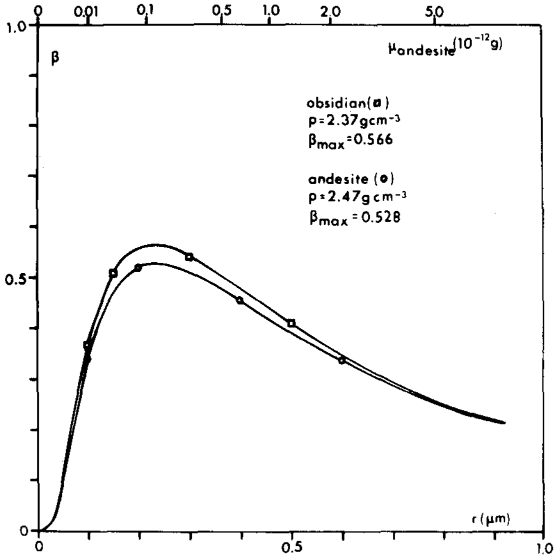

Fig. 2: ß values for Obsidian (□) and Andesite (o); index of refraction after Pollack et al. (1973).

of both curves is very similar with the maximum of ß being about 0.53 for Andesite.

The values have been checked with those given by Lamy (1974), which show a peak value of ß for Andesite to be 0.59. These small discrepencies are due to the fact that the values for the solar radiation used in this paper are more accurate, because for λ > 0.6 μ Lamy used a black body approximation. Even if the bulk of the contribution to the integral for the radiation pressure comes from the region 0.2 to 0.6 μ the approximation of the radiation flux for λ > 0.6 μ causes some inaccuracies.

The most particular fact is that both curves remain smaller than ß = 1 for spherical particles consisting of these nearly pure dielectric materials, where Obsidian is a volcanic glass and Andesite represents stony meteorites. These two models of dust grains will in no case, even with a slightly higher absorption meet the requirement of ß values in the range of 0.9 ≤ ß ≤ 1.1 found for dust particles of the comet Kohoutek (1973 f) by Grün et al. (1976).

A better grain model to meet this requirements would be for example silicate particles with the values of the refractive index tabulated in a paper by Isobe (1975). The ß values for silicate particles are plotted in figure 3.

The lower curve represents the ß values of a purely dielectric quartz particle. This curve has been computed to check the values with Gindilis et al. (1969)

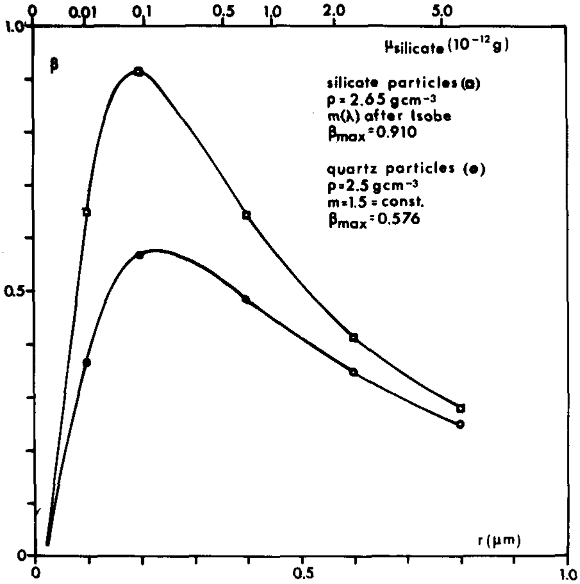

Fig. 3: ß values for silicate particles (□); refractive index after Isobe (1974) and for quartz particles (o) with constant indec of refraction m = 1.5.

where good agreement was found besides the fact that they found their values for the Q_{pr} by interpolation of tabulated values, whereas in this paper in every step of the calculation the exact value of the efficiency factor was used.

The values of the wavelength dependend refractive indices to be found in the literature are in most cases based on measurements of nearly pure crystalline substances, which are not likely to be very good examples of interplanetary dust particles. The real dust particles in space are effected by collisions and sputtering which will change the surface properties very much. Local impurities and radiation damage will change the optical properties of the particle and will lead in the case of radiation damage to a much higher absorption of radiation as was found during sun simulation tests in the Apollo program. To show how the shape of the curves is changed by an increasing absorption in the grain, I have plotted several curves for a fixed real part of the refractive index and variable imaginary part (figure 4). In order to simplify the matter this was done with the refractive index kept constant over the whole range of wavelengths. The corresponding efficiency factors are shown in fig.1.

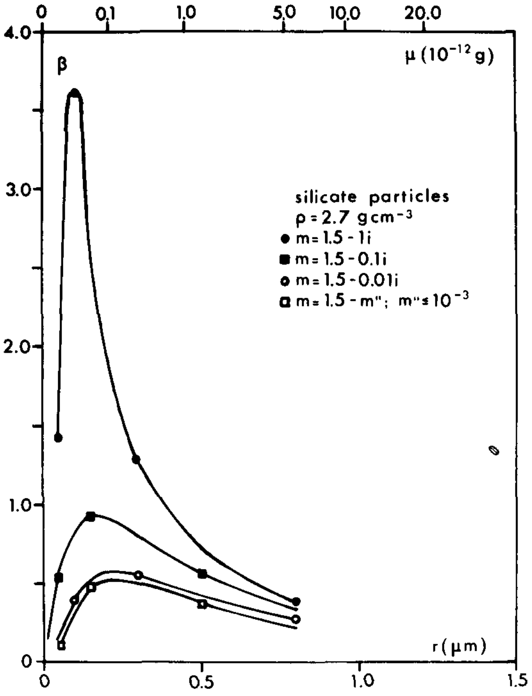

Fig. 4: ß values for different imaginary parts of the refractive index, real part fixed; $\rho = 2.7\ \mathrm{g} \cdot \mathrm{cm}^{-3}$.

The shape of the curve for the dielectric particles is similar to that for Obsidian and Andesite particles (fig.2). With increasing imaginary part of the refractive index, i.e. increasing absorption, the maximum shifts towards smaller radii and the peak becomes very sharp and shows very high values for ß.

This looks very similar to the features of the curve for iron computed with constant index of refraction m = 1.27 - 1.37i as it is often found in the literature.

As already mentioned all the calculation till now have been based on the idealistic assumption of spherical particles and on refractive indices of crystalline substances. Therefore it would be most valuable to learn more about the dynamical behaviour of irregular shaped particles and to get more and more reliable information on the complex indices of refraction for both the visible and infrared region for more realistic materials.

Another problem I would like to indicate is the density of the interplanetary dust grains. If we assume a much lower density than that used in this and most of the other calculations the ß values would be much higher and this would have a very strong influence on the dynamics of the grains.

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Literature

Giese, R.H., Schwehm, G., Zerull, R. 1974, Grundlagenuntersuchungen zur Interpretation extraterrestrischer Zodiakallichtmessungen und Lichtstreuung von Staubpartikeln verschiedener Formen, BMFT-FB W 74-10.

Gindilis, L.M., Divari, N.B., Reznova, L.V. 1969, Sov.Astr.A.J. 13, 114.

Grün, E., Kissel, J., Hoffmann, H.-J. 1976, Dust emission from Comet Kohoutek (1973f) at large distances from the sun, this volume.

Güttler, A. 1952, Ann.Phys. 11, 65.

Isobe, S. 1975, Ann. Tokyo Astron.Obs., Second Series, 14, 141.

Labs, D., Neckel, H. 1970, Solar Phys. 15, 79.

Lamy, Ph.L. 1974, Astron. and Astrophys. 35, 192.

Pollack, J.B., Toon, O.B., Khare, B.N. 1973, Icarus 19, 372.